

# FEM-Based Simulation of a Brushless Resolver

Sorin MIHAI, Alecsandru SIMION, Leonard LIVADARU, Gabriel GHIDUS, Adrian MALANCIUC

"Gheorghe Asachi" Technical University of Iasi

Bd. D. Mangeron, No. 51-53, 700050 Iasi, ROMANIA

mihai\_sorin@ee.tuiasi.ro, asimion@ee.tuiasi.ro, livadaru@ee.tuiasi.ro

**Abstract**—The paper presents a study of a brushless resolver used as angular position transducer. The FEM-based analysis marks out the advantage of rotor windings with sinusoidal distributions. Moreover, the importance of the supply frequency (with a value as higher as possible) in diminution of the error caused by the rotation speed is pointed out.

**Index Terms**—Brushless resolver, finite-element method (FEM), position sensor, sinusoidal distribution winding

## I. INTRODUCTION

The resolvers are usually used as rotor position sensors for the feedback of the automatic control systems or in positioning applications. A higher precision of the resolver requires some compulsory conditions as: advanced manufacturing technology, lack of any eccentricity, proper windings, air-gap and supply frequency.

As regards the constructive structure, the resolvers are two-phase induction machines with wounded rotor. Both rotor and stator have two distributed windings 90 el. degrees shifted in space. The operation is however a synchronous type one with a rotor winding supplied under a frequency in the range 400-10.000 Hz. Generally, the resolvers operate as no-load machines since their load is mainly an operational amplifier with high input impedance. In this case the rotor compensation winding is dispensable.

The analysis proposed in this paper try to point out that a higher supply rotor frequency leads to diminution of the measuring error of the rotation angle. Concurrently, of great importance as regards the magnitude of the output error signal is the shape of the air-gap magnetic field and mainly the content in high order harmonics.

## II. RESOLVER DESCRIPTION

A cross-section of the analyzed resolver is presented in Fig. 1. This is a machine with  $2p=2$  and 16 stator slots and 20 rotor slots. The rotor windings have a particular design, which must determine an air-gap magnetic field as sinusoidal as possible. For this purpose, the slots host a different number of turns – "sinusoidal type" winding – Fig.2. A similar strategy is applied to the stator windings too [3]. The geometric and electric parameters are presented in Table I.

TABLE I. CONSTRUCTION AND ELECTIC PARAMETERS

Item	Value
Inner stator diameter	23 mm
Outer stator diameter	35 mm
Inner rotor diameter	22.7 mm
Shaft diameter	10 mm
Input rated voltage	4 V
Transformation ratio	0.5
Input rated frequency	7 kHz

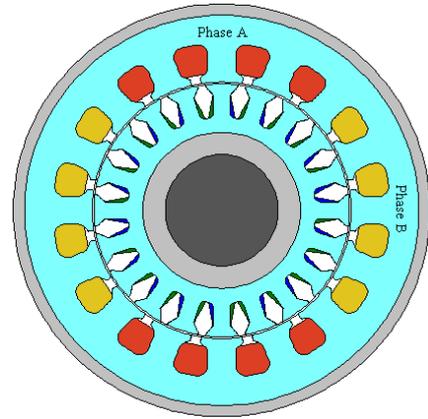


Fig. 1 Resolver cross-section

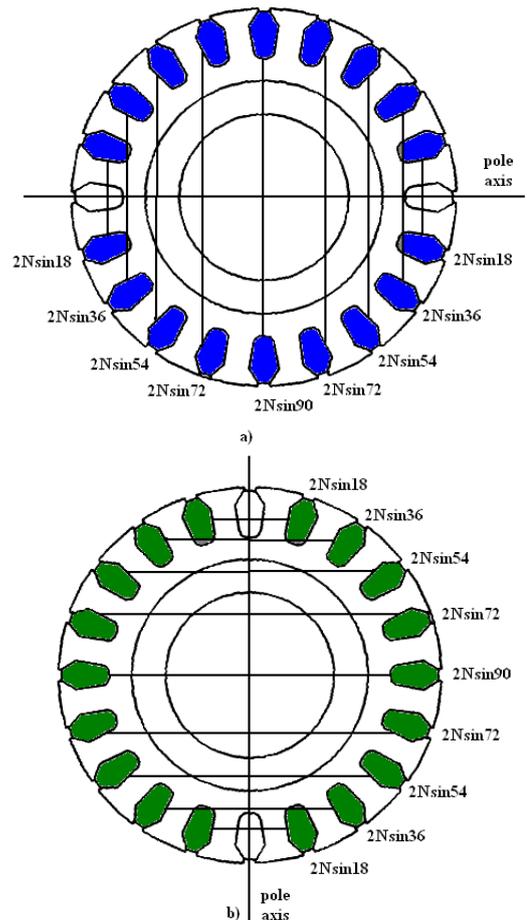


Fig. 2 Rotor windings with unequal number of turns/slot

## III. EQUATIONS

The schematic diagram of the position transducer (resolver) with the two stator windings and the rotor excitation and compensation windings is presented in Fig. 3.

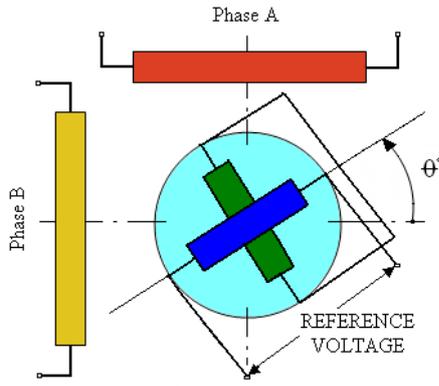


Fig. 3 Schematic diagram of the SIN-COS resolver

The sinusoidal supply voltage applied to excitation rotor winding, having the expression (1)

$$u_e = U_e \sqrt{2} \sin \omega_e t \quad (1)$$

creates an alternating flux, which statically induces two voltages of the frequency  $f_e = \frac{\omega_e}{2\pi}$  ( $f_e = 7\text{kHz}$ )

$$\begin{aligned} u_{A0} &= -E_{Am} \sqrt{2} \sin \omega_e t \cdot \cos \theta \\ u_{B0} &= -E_{Bm} \sqrt{2} \sin \omega_e t \cdot \sin \theta. \end{aligned} \quad (2)$$

These two voltages, which represent the no-load output quantities, have a *sinus-cosinus* proportional magnitude to rotor position. In other words, the relative position of the excitation rotor winding towards stator windings determines the following two induced voltages

$$\begin{aligned} E_{A0} &= E_{Am} \cdot \cos \theta \\ E_{B0} &= E_{Bm} \cdot \sin \theta, \end{aligned} \quad (3)$$

where  $E_{Am}$  and  $E_{Bm}$  correspond to induced no-load voltages in Phase A and Phase B when the excitation winding axis is collinear to each stator winding axis.

#### IV. TRANSIENT AND MAGNETODINAMIC FEM ANALYSIS

The simulation under transient conditions took into consideration a rotating frequency of 100 Hz. As regards the supply frequency, three situations have been taken into discussion: 7 kHz (case A), 10 kHz (case B) and 5 kHz (case C). Finally, a fourth situation has been analyzed: the "sinusoidal type" rotor winding has been replaced with a common winding (equal number of turns/slot) and supplied with 7 kHz frequency (case D).

Fig. 4 presents the flux lines distribution and flux density color map corresponding to case A. It has to be pointed out the low values of the flux density of the magnetic circuit.

The movement of the rotor determines induced stator voltages of "rotational type". The carrier frequency is of 7 kHz (Fig. 5) and there is a modulation of the amplitude described by two sinusoidal waves 90° shifted in time.

When  $\theta = 0^\circ$ , the induced voltage is maximum in Phase A and has zero value in Phase B. The situation becomes vice versa for  $\theta = 90^\circ$ .

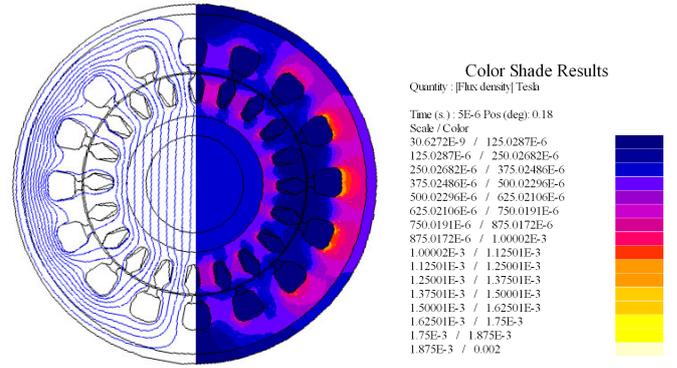


Fig. 4 Flux lines distribution and flux density color map – Case A

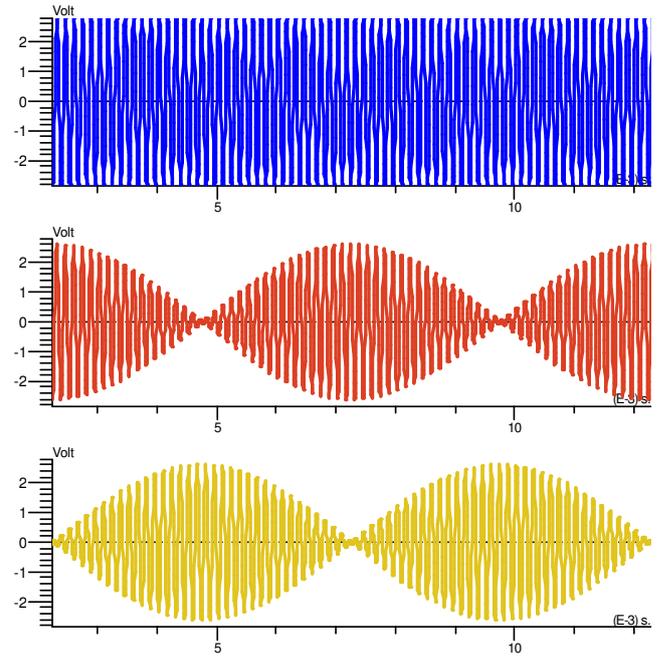


Fig. 5 Rotor and stator voltage variation – Case A

The rotor ampere-turn created by the excitation winding determines an air-gap flux density distribution, which by means of a Fourier expansion can be expressed.

The analyses put in view that both stator and rotor windings are responsible for the errors magnitude due to high order harmonics created by the space distribution. Consequently, a diminution of the high order harmonics is necessary. A possible solution is the "sinusoidal type" winding.

Fig. 6 shows the air-gap flux density wave and its content in high order harmonics when the rotor winding have equal distributed turns/slot (case D). Fig.7 presents the modulating excitation voltage and the output modulating voltage (the time representation corresponds to its maximum value). One can see that mainly the presence of the 3<sup>rd</sup> and 5<sup>th</sup> high order harmonics determines a decrease of the output voltage in comparison with the reference (excitation) voltage.

An increase of the output voltage can be achieved by improving the shape of the air-gap flux density. The use of "sinusoidal type" windings determines a significant diminution of the 3<sup>rd</sup> order harmonic and canceling of the 5<sup>th</sup> order harmonic (Fig. 8, Fig. 9).

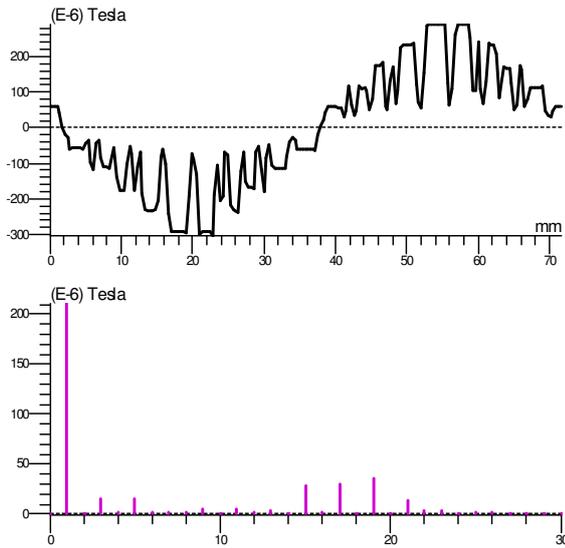


Fig. 6 Air-gap flux density and content in high order harmonics – Case D

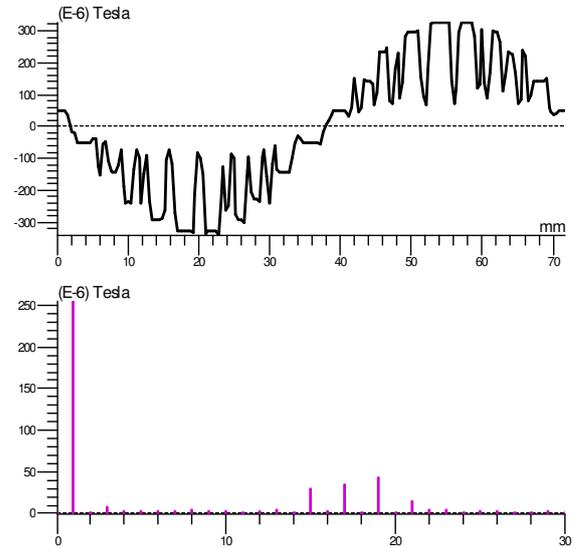


Fig. 8 Air-gap flux density and content in high order harmonics – Case A

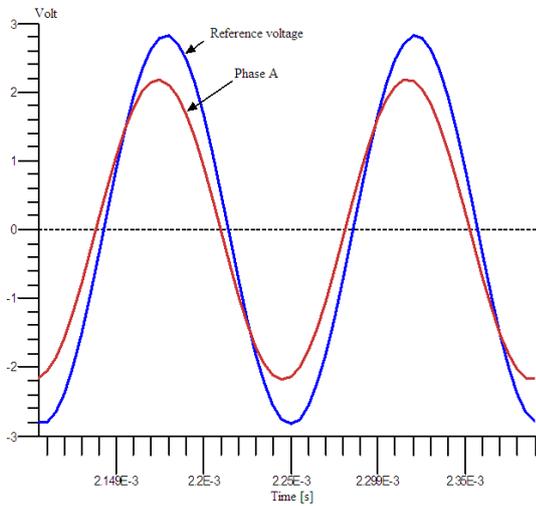


Fig. 7 Modulating voltages – Case D

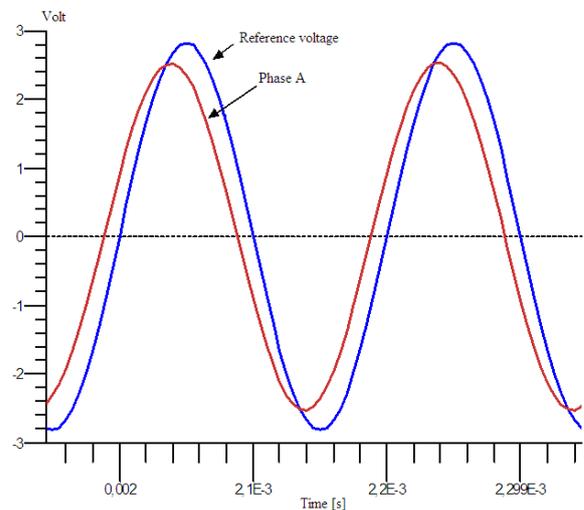


Fig. 9 Modulating voltages – Case A

A supply frequency with a value as higher as possible is justified in Fig. 10. The output voltage has a nearly sinusoidal shape. The evaluation of the rotation angle,  $\theta$ ,

can be achieved by demodulating and filtering. The result comes out as two sinusoidal signals  $90^\circ$  shifted in phase.

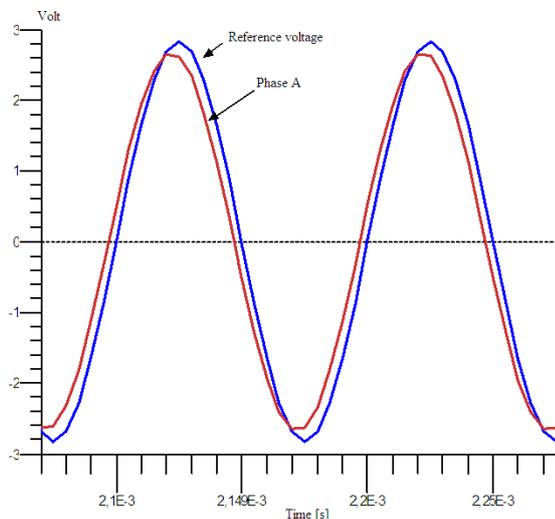


Fig. 10 Demodulated output voltages – case B

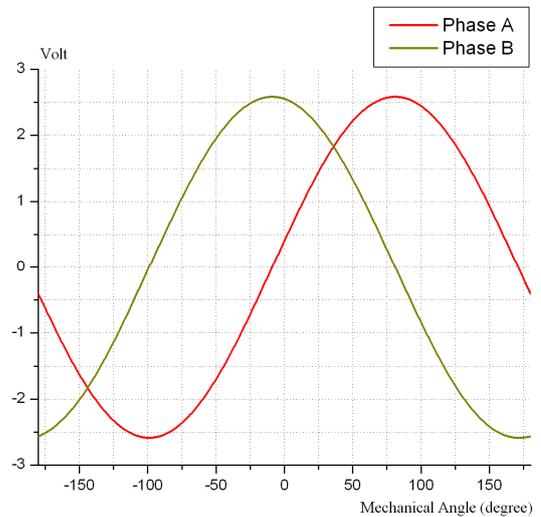


Fig. 11 Processed output voltages – Case A

The comparative analysis for the four proposed cases is presented in Fig. 12. One can see that a higher supply frequency determine a higher amplitude of the output voltage and consequently, lower measuring errors. The type of the windings (sinusoidal type or regular) has an important influence too.

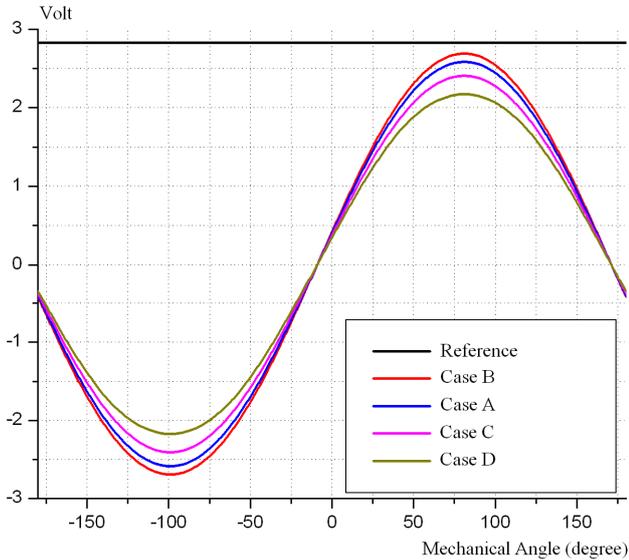


Fig. 12 Output voltage versus rotation angle dependence

## V. CONCLUSION

The paper presents a FEM-based analysis of a resolver for two distinct situations:

- i) rotor windings with equal number of turns/slot and
- ii) rotor windings with different number of turns/slot ("sinusoidal type" distribution).

The second solution determines an improvement of the shape of the air-gap flux density wave and consequently a diminution of the high order harmonics effects. Thereby, the measuring errors of the position angle come to a lower limit.

A second study analyzed the influence of the supply frequency, which generally does not remain constant during

the operation of the transducer. This fact concerns the accurate evaluation of the position angle. For a proper operation, a stabilizing of the supply rotor frequency is necessary mainly for those applications that operate at high speeds.

## REFERENCES

- [1] L. Sun, "Analysis and improvement on the Structure of variable reluctance resolver", *IEEE Trans Mag.*, vol. 44, no. 8, pp. 2002-2008, August 2008.
- [2] K. C. Kim, C. S. Jin, J. Lee, "Magnetic shield design between interior permanent magnet synchronous motor and sensor for hybrid electric vehicle", *IEEE Trans Mag.*, vol. 45, no. 6, pp. 2835-2838, July 2009.
- [3] S. Mihai, A. Simion, L. Livadaru, "Fem-based analysis concerning some solutions on the restriction of the space high order harmonics of the two-phase induction machine", *Bul. Inst. Polit. Iasi, Tomul LIV(LVIII), Fasc.4*, pp. 933-938, 2008.
- [4] D. A. Khaburi, F. Tootoonchian, Z. N. Gheidari, "Parameter Identification of a brushless resolver using change response of stator current", *EE, Journal of Electrical*, vol. 3, no. 1 & 2, pp. 42-52, Jan. 2007.
- [5] D. C. Hanselmar, R. E. Thibodeau, D. J. Smith., "Variable-reluctance resolver design guidelines," *IEEE IECON*, New York, pp. 203-208, 1989.
- [6] L. Z. Sun, J. B. Zou, Y. P. Lu, "New variable-reluctance resolver for rotor-position sensing, *IEEE conference*, pp. 5-8, 2004.
- [7] R. Setbaken, "System performance and application tradeoffs determine the choice between encoders and resolvers in brushless servos," *Power converters, Intell, Motion*, vol. 22, no 5, pp.69-76, 1996.
- [8] M. Benammar, L. B. Brahim, M. A. Alhamadi, "A high precision resolver to dc converter," *IEEE Trans. Instrum. Meas.*, vol. 54, no. 6, pp. 2289-2296, Dec. 2005.
- [9] F. J. Wan, X. Li, G. Hong, "The analysis and design of high-speed brushless resolver plus R/D converter shaft-angle measurement system," in *Electr. Mach. Syst., ICEMS*, pp. 289-292, 2001.
- [10] D. C. Hanselman, "Techniques for improving resolver-to-digital conversion accuracy," *IEEE Trans. Ind. Electron.*, vol. 38, no. 6, pp. 501-504, Dec. 1991.
- [11] A. Simion, *Special electric machines for automatics (in Romanian)*, Universitas, Chisinau, 1993.
- [12] [www.moog.com](http://www.moog.com), *Synchro and Resolver Engineering Handbook*, MOOG Components Group, 2004.
- [13] K. Masaki, K. Kitazawa, H. Mimura, K. Tsuchimichi, H. Wakiwaka, H. Yamada, "Consideration on the angular error due to the shaft eccentricity and the compensation effect by short-circuit winding on a resolver," *J. Magn. Soc. Jpn.* 22, pp. 701-704, 1998.